

SUSTAINING AND ENHANCING HIGH OPTEMPO PERFORMANCE OF SOLDIERS IN THE TRANSFORMED MILITARY

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1. BACKGROUND

The state of warfare over the past several decades has rapidly evolved, requiring an equally agile adaptation by Army forces. Two decades previous, threats to our nation came from superpower struggles initiated by large adversarial nations such as The Soviet Union. Today, emerging dominant nations and aggressive meta-national entities based within failing states are the greatest menace to the security and safety of our nation. Not only the nature of the antagonist, but also the characteristics of the threat have radically changed. Enemy forces have accrued asymmetric battle capabilities and have generated an environment of unpredictable and diverse exchanges. This new standard for modern conflict has led to the necessity for adaptability of both the individual and teams of individuals. Part of the response by the Army has been to assemble a dense information network that markedly increases data collection and dissemination. In a related effort, novel computer models and algorithms have been employed in the fusion of multimodal data into a display format that can be readily comprehended by the Operator. While the technological aspects of improved surveillance and information flow have been well explored, focus has recently broadened to include improved tasking abilities of individual Soldiers. In this endeavor, Soldier perceptual and comprehension skills are augmented via neuroergonomic technologies, training techniques, and informed sleep schedules.

Within a 10-year timeframe the authors anticipate that the cognitive and physiological state of individual Soldiers will be autonomously and remotely measured, and fused to create standardized metrics of unit-level preparedness. In the full realization of this “Commander’s Dashboard”, the Commander will be armed with a simple iconographic

visual display platform exhibiting standardized metrics representing the physical, physiological, and cognitive state of the Soldiers under his or her command. Thus as the Soldiers carry out their duties according to their sleep schedules, cognitive workloads, and physical exertion within the operational environment, the Commander will be able to monitor the status of the unit in real-time. This information can be used for status updates to higher Command, risk mitigation for individual missions, adjustment of planned activities or individual duties, or for investigating the dependence of mission success on various determinants. This technology will furthermore generate baseline and longitudinal data on individual Soldier health that will improve training and mission success. Attaining capability in the online real-time monitoring of soldier and unit state, and improving individual capability to withstand stress, sleep-deprivation, intense physical activity, and cognitive decrement during high optempo long time-on-task can be achieved in the near-term. To do so requires the identification of the fundamental cognitive and physiological mechanisms underlying change in abilities due to stress, etc. Once the salient mechanistic traits have been determined, surrogate measures should be identified that can be recorded by rugged, low-footprint, deployable sensors. Because knowledge of the data output (sensor recordings, metrics, and data transmission) may lead to altered self-perception and a change in behavior, the availability of information to individual Soldiers should be regulated.

The current focus on the human component of warfare will be a key determinant of success on the battlefield. Helping our Soldiers to improve their observation and scanning abilities, cognitive assessment

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of threat, rapid decision-making under stress, and extended time-on-task abilities will form the basis for the required adaptability of our Force in modern asymmetric warfare. One of the most prevalent consequences of warfare is a lack of adequate rest. Soldiers engage in frequent, long-duration scouting missions in extreme environmental conditions such as excessive heat and dust, and then return to base to engage in the completion of further duties. To manage these challenges, Commanders may forego sleep for multiple days at a time. Likewise, the Soldiers under their command can receive as little as 0-5 hours of sleep per night for the duration of deployments lasting 12-15 months. In those situations for which adequate sleep is not possible, it would be of value for the Army to understand which skills and abilities are most resilient to sleep deprivation, to pinpoint the underlying brain activity changes, and to determine which remote and reliable measures can serve as a surrogate for metrics that are difficult to measure in mobile individuals in a rugged environment.

Our research, ‘Sustaining and Enhancing High Optempo Performance of Soldiers in the Transformed Military’ is led by the Center for Strategic and Innovative Technologies (CSIT) at the University of Texas at Austin. The results of this research will characterize changes in cognition and physical performance due to 36 hours of sleep deprivation, including constant time-on-task and intermittent exercise to exhaustion. In addition, the effects of extended periods of sleep deprivation for 8 days were tested using Norwegian Cadets in training. The findings presented in this paper were generated by a team of scientists at the University of Texas at Austin (Drs. Steve Kornguth, Rebecca Steinberg, David Schnyer, Logan Trujillo, Todd Maddox, Art Markman, and Ed Coyle), Baylor College of Medicine (Dr. David Eagleman), the Army Research Laboratory Human Research & Engineering Directorate (ARL-HRED) (Carita DeVilbiss and Valerie Rice), and the U.S. Military Academy at West Point (USMA) (Drs. Michael Matthews and James Merlo). From the projects described in this paper, it has been possible to identify the regions of neural activity, cognitive abilities, and performance and physiological characteristics that are most robustly altered by sleep deprivation, as well as those that remain relatively unaffected. These deliverables will enable Soldiers on the field to maintain decision-making abilities, manage sustained operations, comprehend high rates of data presentation, and augment leadership effectiveness and cognitive flexibility. From these metrics, a model of human performance under sleep deprivation and physical strain is being developed for use in high optempo training. We are also investigating the use of optimized auditory, visual, and tactile cues for improved signaling communication, and for maintaining and renewing concentration to task. A man-portable lightweight device for tracking whole-brain distributed processing speed using chronometry perception is being

tested for use in training for extended high optempo missions. The results of our research will contribute greatly to the development of the “Commander’s Dashboard”. Our research may also enable the identification of nutritional amendments that will sustain performance.

2. TOOLS

Our team employs several cutting-edge technologies to the study of human performance research, including structural and functional magnetic resonance imaging (MRI and fMRI), electroencephalography (EEG), computerized cognitive tests, and exercise to exhaustion with simultaneous recording of vascular/pulmonary/muscular parameters and physical output and endurance. The MRI magnet is a large, ~1-2 ton stationary device that must be housed in a magnetically protected infrastructure. Modifying different aspects of the radiofrequency pulse sequence can generate images highlighting different structural architectures of the brain, or regions of high metabolic activity characterized by hemoglobin deoxygenation and changes in intracranial blood flow. Structural MRI creates a high resolution (~0.6 mm³) high-contrast image that differentiates gray matter brain tissues from adjacent fluid-filled cavities of the cranium. This technique is valuable for providing a high-resolution 3-D map of the brain. Our team will use structural MRI to quantitatively compare the size of brain nuclei across different individuals (sulcal and gyral divisions of the cerebrum, hippocampus, amygdala, lateral ventricles, caudate, lenticulate (putamen and globus pallidus) and thalamus). These data can be used to determine whether inter-individual variability in brain nucleus size correlates with inherent resilience or susceptibility to the detrimental effects of sleep deprivation. Another MRI technique used by our team is diffusion tensor imaging (DTI), which employs the same hardware but uses different pulse parameters to highlight instead the white matter tracts that serve as information conduits between different brain regions. As with the gray matter regions, it is possible that differences in white matter tractography may explain inherent differences of ability during extended periods of sleeplessness. DTI uses the vector strength of water diffusion directionality to infer the location of fiber bundle pathways. Because water diffusion is more limited to the longitudinal dimension of the fiber tracts, the fractional anisotropy (FA) value is higher, especially in large, dense fiber bundles. Individual differences of FA values in these regions may relate to a higher degree of myelination of those fibers resulting in faster conduction times. Functional MRI measures the degree of deoxygenation of hemoglobin and intracranial blood flow, that indicate which brain regions are most metabolically active. Functional MRI is a time-averaging assay having

excellent spatial but poor temporal resolution. In contrast, EEG has poor spatial but very good temporal resolution. We used a 71-channel EEG device to record alpha wave brain activity. The computerized cognitive tests used in our study include a working memory 2-back test as well as a computational simulation called the General Exploration Model (GEM) that tests the effects of sleep deprivation on behavioral strategy bias. In the study on long-term sleep deprivation with Norwegian Cadets, a “Texas Battery” of three assays produced multiple metrics for measuring distributed brain processing of time.

3. METHODS

The goals of this study are to test four groups, each containing 20 male and 20 female participants: (1) Fort Hood First Cavalry Division Soldiers, (2) West Point USMA Cadets, (3) The University of Texas at Austin Reserve Officers’ Training Corps, Longhorn Division, (4) Age- and sex-approximated non-military persons. The results discussed in this study focus on the first two groups. The fundamental experimental schedule is as follows: 0600 report to The University of Texas at Austin Imaging Research Center for MRI, DTI, fMRI, GEM, and other cognitive assays; 1300 report to the exercise physiology laboratory of Dr. Coyle at The UT-Austin for exercise to exhaustion and physiological measures, 2-back testing, flicker fusion; 1900 – 0600 dinner, overnight activities with monitor; 0600 report to The UT-A Imaging Research Center for fMRI, GEM, and other cognitive assays; 1300 report to the exercise physiology laboratory of Dr. Coyle at the UT-Austin for exercise to exhaustion and physiological measures, 2-back testing, and flicker fusion. Note that magnetic resonance imaging occurred on Day 2 in the morning, at a state of approximately 24 hours sleep deprivation.

For the 8-day sleep deprivation study, a representative of Dr. Eagleman’s laboratory (Gregory Bohusman) flew to Norway in July of 2008 with 5 desktop computers programmed with the Texas Battery software. Data was collected according to the availability of the Norwegian Cadets during their training mission, which involved near-constant physical activity over the 8-day period followed by 2-5 days of recovery. The first test in the battery, “Flicker Fusion,” is believed to measure central visual processing speed. In this test, the color of a 4-digit number is rapidly interposed with the background color until a characteristic flicker rate is reached at which the number becomes so blurry as to be illegible. The second test, “Temporal Order Judgment” task (TOR) records the Soldier’s time perception in relation to his/her actions. In this task, the Soldier volunteer clicks a white box, which then jumps to another spot in a grid. Occasionally, the box jumps prior to being clicked, and the Soldier is then required to declare the perceived order of events. The third

task, “Visual Persistence”, is equivalent to an inverse change-detection task. Out of a grid of 25 squares, 12 flash white then disappear, then a different 12 flash white. The participant must designate which square was never lit up.

3. RESULTS

1. Functional MRI, simulation, and decision-making results (Schnyer)

Both Soldiers and Cadets exhibited a decline in performance on the simple decision-making task on Day 2. For the complex decision-making task, Cadets performed at a high level on Day 1, but their performance declined significantly on Day 2. Soldiers performed at a lower level on Day 1, but maintained their scores on Day 2, at which point Cadets and Soldiers performed equivalently. Findings indicate that a profound decline in complex decision-making (28%) abilities in male West Point subjects on Day 2 was associated with predominant loss of brain activation in the prefrontal and parietal cortices during fMRI. It is notable that complex decision-making abilities in Fort Hood soldiers did not significantly decline on Day 2, and neither did their prefrontal cortical activity during the complex decision-making task. Functional brain activity during the humvee virtual reality simulation has not yet been fully analyzed for Fort Hood soldiers. Cadets.

The Fort Hood Soldiers (who returned from deployment, Operation Iraqi Freedom, in January 2008) also performed differently from Cadets in the humvee virtual reality scenario during sleep deprivation. Cadets became slower at detecting a threat on Day 2, but maintained their accuracy. Soldiers were faster at event detection on Day 2, but they completely missed additional threats, and incorrectly judged harmless stimuli to be a threat.

Brain activity during the visual motor control task was higher in the right anterior prefrontal cortex on Day 1, but this laterality was not present on Day 2. Furthermore, on Day 2, laterality of brain activity no longer correlated with performance scores.

Table 1: Summary of significant changes in Cadet and Soldier behavior and brain activation after 24 hours of sleep deprivation.

		Complex Decision-Making	Virtual Reality Humvee
Behavior	USMA Cadets	Stronger performance Day 1, 28% performance decline Day 2	Slower event detection Day 2, but accuracy remains ~the same.
	Ft. Hood Soldiers	Weaker performance Day 1, 0% performance decline Day 2	Faster event detection Day 2, but lower accuracy and more threats missed
Imaging	USMA Cadets	fMRI major decrease in prefrontal & parietal cortices	fMRI major decrease in anterior cingulate and left insula
	Ft. Hood Soldiers	fMRI slight decrease in brain activity	[Under Analysis]

2. Structural MRI (Diffusion Tensor Imaging) (Schnyer)

Soldier DTI data is undergoing analysis, and so the data presented below include only from West Point Cadets. This study focused on the genu of the corpus callosum, a large white matter tract connecting the left and right prefrontal cortices. The decrease in accuracy on a visual motor control task from Day 1 to Day 2 was calculated for each participant, and a median split was performed. Individuals with the greatest decline in ability were defined as the “vulnerable” group, and the remaining were termed “non-vulnerable.” The FA values of the vulnerable group were found to be significantly lower than those of the non-vulnerable group (See Figure 1).

Figure 1. Fractional Anisotropy Values in the Genu of the Corpus Callosum

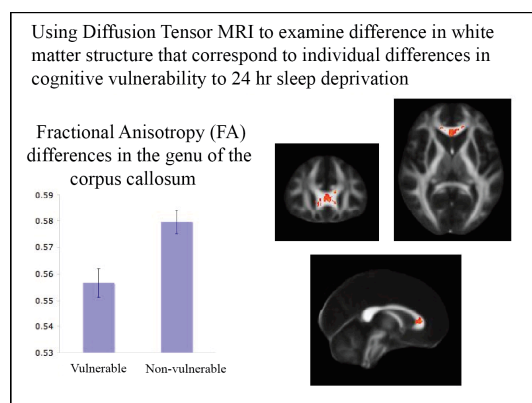


Fig. 1 Participants found to be “vulnerable” to sleep deprivation had lower FA values in the genu of the corpus callosum than the “non-susceptible” group. The regions of the corpus callosum exhibiting these differences are shown in the MRI brain maps at right.

3. EEG of Alpha Wave Activity (Trujillo)

Alpha wave activity brain activity typically has greater magnitude when the eyes are closed versus when they are

open. The “alpha wave power” is defined as the difference in alpha wave activity between eyes open and eyes closed. In sleep-deprived subjects on Day 2, we observed a decrease in the alpha power. Both Soldiers and Cadets showed a significant decrease in eyes closed alpha wave activity from Day 1 to Day 2, but whereas Soldiers showed a similar decline for the eyes open condition, Cadets did not. The result was that Soldier alpha power did not decrease on Day 2, whereas Cadet alpha power did.

Figure 2. Cadet Alpha wave graph

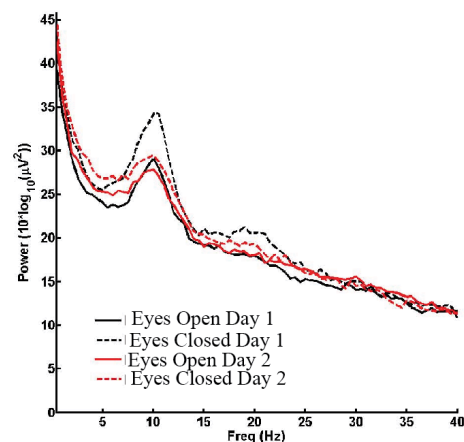


Fig. 2 In the graph above, alpha wave activity in the 8-12 Hz range is shown as either black (Day 1) or red (Day 2), solid (eyes open) or dotted (eyes closed). Alpha power, the subtraction of the peak alpha wave activity in the eyes open from that of the eyes closed state, decreases significantly on Day 2.

Figure 3. Soldier alpha wave graph

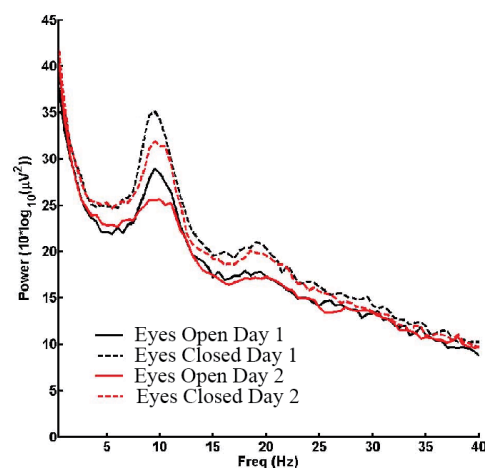


Fig. 3 For Soldiers, the alpha power remains the same on Day 2 as on Day 1. This finding correlates with a

maintenance of abilities and brain activity on Day 2 in the decision-making tasks.

4. General Exploration Model (Maddox, Markman)

This video game tool measured the behavioral strategy of participants in different situations associated with different inexplicit reward mechanisms. In the Exploration-reward scenario, players gain more points by roaming about the playing field in search of high-value points. In the Exploitation-reward scenario, players get a higher score by staying within a region of high frequency low-value points. Whereas the Control group that was able to rest overnight improved in score from Day 1 to Day 2 on both tasks, the sleep-deprived Cadets exhibited poorer abilities in the Exploitation task on Day 2, but improved abilities in the Exploration task. Indeed, their improvement in Exploration on Day 2 was significantly greater than that of Controls.

5. Physiological Measures (Coyle)

The parameters of time-to-exhaustion, maximal oxygen consumption, maximal blood lactate concentration, and neuromuscular power did not change in participants undergoing exercise to exhaustion on a bicycle ergometer at 12 and 36 hours after awakening. In addition, the working memory 2-back test, and flicker fusion test showed no change in performance on Day 1 or Day 2.

6. Texas Battery Test on Norwegian Cadets Undergoing 8 Days of Sleep Deprivation (Eagleman)

The Texas Temporal Battery contains three tests: Flicker Fusion, Visual Persistence, and Causality Judgment. Results showed that scores on these three measures remained constant until 52 hours of sleep deprivation, at which point scores steeply decreased and remained poor until two days of recovery.

4. DISCUSSION

Overall, the West Point USMA Cadets performed with higher scores than Fort Hood Soldiers on Day 1, however their measured abilities and brain activity declined on Day 2 (fMRI and behavior scores). In contrast, the brain activity and measured performance of Fort Hood Soldiers did not change during sleep deprivation. The Soldier cohort also did not have decreased alpha power on EEG readings. The decremented scores and brain activity of Cadets on Day 2 resembles the sustained performance of the Soldiers. These findings suggest that alpha power, which can be recorded with a simple 2-lead system that can be adapted for a helmet, may be an adequate proximal measure for loss of cognitive function during sleep deprivation. In the near future, we will investigate whether

an individual's EEG alpha power readings are a valuable metric for predicting performance. Laterality of brain functional activity in the prefrontal cortex was lost during sleep deprivation, and this correlated with a decline in abilities. Furthermore, we observed decreased fractional anisotropy scores in the genu of the corpus callosum (which connects both hemispheres of the prefrontal cortex) in those individuals highly susceptible to sleep deprivation. In the future, we will investigate whether intrinsic differences in white matter properties, measured through DTI, might be correlated with maintenance of brain function laterality during sleep deprivation. We hypothesize that these intrinsic differences in white matter fractional anisotropy between susceptible and non-susceptible individuals may result from brain developmental effects. Observed differences in behavior and brain activity on Day 1 between Soldiers and Cadets is most likely due to differences of baseline sleep-deprivation levels due to scheduling, experience, and training. In the General Exploration Model, we hypothesize that the observed change in strategy on Day 2 to a biased exploratory behavior is the result of weakening of rule-based behaviors. The "rule" that it is better to remain where points are abundant is overshadowed in Cadets on Day 2 by an increased tendency to wander about the playing field, thereby encountering a greater number of high-value points. That physiological measures and exercise ability do not change during sleep deprivation is a very positive finding, given the need to maintain a high level of physical activity in the battlefield arena.

5. CONCLUSION

The findings of this study will be used to improve the Soldier's ability to maintain cognitive skills during periods of sleep deprivation such as those associated with wartime deployment. Our results show that differences of training and experience may confer resilience or susceptibility to the effects of sleep deprivation. Furthermore, our group has shown that altered brain activity during sleep deprivation may be a root cause for decreased abilities in complex decision-making tasks, and threat perception. The Texas Battery results suggest that while global time perception and visual processing speeds are maintained during two days of wakefulness, these abilities steeply decline after that point. Our study found that participants' exercise capabilities are entirely preserved during sleep deprivation. The fact that cardiovascular, pulmonary, and skeletal muscle physiological measures and exercise ability do not change during sleep deprivation is a very positive finding, given the need to maintain a high level of physical activity in the battlefield arena. By discovering which skills and abilities are negatively affected by sleep deprivation (complex decision-making, vigilance, visual processing, time

perception) our group has taken a first necessary step towards devising countermeasures.

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